

MOBILE WIRELESS LOCAL AREA NETWORK AND RELATED METHODS

FIELD OF THE INVENTION

[0001] The present invention relates generally to communication systems on board mobile platforms such as aircraft and, more particularly, to an on-board wireless local area network (WLAN) accessible by passengers' portable electronic devices such as laptop computers.

BACKGROUND OF THE INVENTION

[0002] Mobile network systems have traditionally been limited in bandwidth and link capacity, making it prohibitively expensive and/or unacceptably slow to distribute broadband data and video services to all passengers on a mobile platform such as an aircraft, boat or train. There is great interest in making such services available to users on mobile platforms. A system for supplying television and data services to mobile platforms is described in co-pending United States Patent Application No. 09/639,912, the entire disclosure of which is incorporated herein.

[0003] The system described in Application No. 09/639,912 provides bi-directional data transfer via satellite communications link between a ground-based control segment and a mobile RF transceiver system carried on each mobile platform. Each user on each mobile platform is able to interface with an on-board server by using a laptop, personal digital assistant (PDA) seat-back-mounted computer/display or other computing device. Each user can independently request and obtain Internet access,

company intranet access, stored video and audio programming and live television programming.

[0004] It would be desirable to provide passengers with wireless connections to network services available on mobile platforms such as aircraft. There are concerns, however, about the possibility of interference to aircraft systems from portable electronic devices (PEDs) that might be used by passengers to make wireless connections to an on-board network. Of particular concern is the possibility of PED interference during critical phases of flight, for example, during takeoff and landing. There also are concerns that such networks might expose passengers and flight crews to radiated RF fields exceeding recommended health and safety limits for RF exposure.

[0005] Generally there are two types of PEDs: (1) intentional transmitters, which must transmit a signal in order to accomplish their function (e.g. cell phones, two-way radios, pagers and remote-control devices), and (2) non-intentional transmitters, which do not need to transmit a signal to accomplish their function, but nevertheless emit some level of radiation (e.g. laptop computers, compact disk players, tape recorders and electronic hand-held games). The Federal Aviation Administration (FAA) has not issued certification regulations for PEDs. The FAA does, however, restrict the use of PEDs on commercial airlines. FAA advisory circular AC91.21-1 paragraph 6.a (7) states that, unless otherwise authorized, use of PEDs classified as intentional transmitters should be prohibited during aircraft operation. General Operating and Flight Rules, 14 CFR 91.21(b)(5) ("Portable Electronic Devices") prohibits the operation of a PED on an aircraft, unless the aircraft operator has determined that the device will not cause interference with the navigation or communication systems on board the aircraft.

Thus it is desirable to provide a wireless network that can be determined to be accessible by passenger-operated PEDs without causing such interference and thus could be authorized for on-board use. It also is desirable to provide an on-board wireless network that produces RF emission levels within recommended health and safety limits.

SUMMARY OF THE INVENTION

[0006] In one preferred form, the present invention provides a wireless local area network adapted for use by users traveling on a mobile platform such as an aircraft. The network includes a network server located on the mobile platform, and at least one network access point connected to the server and accessible wirelessly by at least one user portable electronic device over one of a plurality of non-overlapping network frequency channels. This wireless local area network can provide two-way communication, data and entertainment for aircraft passengers, cabin crews and flight crews. Such information may be obtained via e-mail, internet, company intranet access, and/or from data stored on board or off board the aircraft. The RF characteristics of this wireless network are specifically tailored to meet applicable standards for electromagnetic compatibility with aircraft systems and RF exposure levels for passengers and flight crews.

[0007] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred

embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0009] Figure 1 is a view of a wireless LAN ("WLAN") adapted for use in a mobile platform such as an aircraft;

[0010] Figure 2 is a plan view of WLAN cells in an aircraft passenger cabin, shown from above the overhead area;

[0011] Figure 3 is a graph of E-field strength of emissions versus transmitter-to-victim distance for a WLAN;

[0012] Figure 4 is a view of a portion of a passenger cabin, shown from above the overhead area, in which more than one user PED is in use; and

[0013] Figure 5 is a graph of margins of compliance with FCC OET Bulletin 65 for the effect of adjacent laptops on RF exposure versus distance from transmitter.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0014] The following description of the preferred embodiments is merely exemplary in nature and is in no way intended to limit the invention, its application, or uses. As described below, the present invention in one embodiment is directed to a wireless LAN ("WLAN") for use in a mobile platform. The mobile platform could include an aircraft, cruise ship or any other mobile vehicle. Thus the reference to the mobile

platform as an aircraft throughout the following description should not be construed as limiting the applicability of the WLAN 10 and/or the present invention to only aircraft.

[0015] A preferred embodiment of a wireless LAN for use in a mobile platform such as an aircraft is indicated generally by the reference numeral 10 in Figure 1. The WLAN 10 includes an Ethernet router/server 14 (hereinafter "server") wired to a plurality of access points 18 via at least one switching device such as an Ethernet switch 22. In the embodiment shown in Figure 1, the server 14 is connected to a transmit antenna, in this example, a transmit phased array antenna system 26, and to a receive antenna, which in this example comprises a receive phased array antenna system 30. The antenna systems 26 and 30 provide for two-way communication via satellite link between the WLAN 10 and a ground based network segment, as described in co-pending United States Patent Application No. 09/639,912. The server 14 can interface with other systems, for example, with in-flight entertainment and/or telephone service systems. In another embodiment the WLAN 10 operates standalone in the mobile platform.

[0016] Each access point 18 has an antenna 34 located, for example, in the passenger cabin overhead. Each access point 18 is configured to transmit RF signals to, and receive RF signals from, one or more PEDs 38 carried on board by passengers. Such PEDs are fabricated for wireless use or have a wireless adapter antenna (not shown) and can include laptops, PDAs or the like. The access point antenna 34 may be, for example, an omni-directional or patch antenna. The number and location of access points 18, and the number of PEDs 38 associated with an access point 18, can vary as further described below.

[0017] An exemplary arrangement of access point antennas 34 relative to PEDs 38 is shown in Figure 2, which is a plan view of a portion 76 of an aircraft passenger cabin. Two access points 18 (not shown in Figure 2) and associated antennas 34 are located in the overhead. Although an access point 18 could be located outside the cabin overhead, locating it close to its antenna 34 in the overhead reduces the length of a cable connection between them. Each access point 18 broadcasts over a cell 80 that includes eighteen seats 84. Other cell sizes and numbers of associated seats can be used, as further described below. Factors influencing the sizes and numbers of cells 80 include seat width 92, seat pitch 96, distance 100 between antennas 34, interior width 104 of the cabin, and the width 108 of each of the rows of seats 84.

[0018] The WLAN 10 operates in the 2.40 to 2.483 GHz ISM band, which is designated for unlicensed commercial or public use. Other licensed or unlicensed bands above 2.4 GHz, for example, the ISM 5.725 to 5.875 GHz band, could also be used. The WLAN 10 is configured in conformance with the IEEE 802.11b (High Rate) standard. The invention is not so limited, and other bands, standards, and protocols can be used. Each access point 18 communicates with the server 14 through the Ethernet switch 22 at full available bandwidth. The WLAN 10 utilizes Direct Sequence Spread Spectrum (DSSS) transmission between each access point 18 and its associated user PEDs 38. That is, the spectrum is divided into three non-overlapping frequency channels of approximately 22 MHz each. It is contemplated that other spread-spectrum modulation methods also could be used.

[0019] Each access point 18 is configured to communicate with PEDs 38 over one of the three channels. For example, as shown in Figure 1, three access points 18 communicate using channels 1, 6 and 11 respectively. Adjacent access points 18 broadcast over different channels. For example, referring to Figure 2, a user sitting in a cell 80 in which the associated access point 18 broadcasts over channel 1 could communicate with the WLAN 10 via channel 1. Another passenger sitting in an adjacent cell 80 would communicate with the WLAN 10 over channel 6 or channel 11.

[0020] Where the number of access points 18 exceeds three, each channel can be re-assigned to another access point 18 that is not adjacent to an access point to which the channel is already assigned. For example, seven access points 18 located sequentially along the aircraft aisle overhead could use channels 1, 6, 11, 1, 6, 11 and 1 respectively. Thus use of each of the three channels can be distributed spatially over the aggregate of cells 80, for example, to users distributed over the entire passenger cabin. Of course, the channels can be distributed over a plurality of cells in many different ways. Additionally, a connected user PED 38 can roam, e.g. as supported by the IEEE 802.11b protocol. That is, a WLAN 10 connection established with a user PED 38 in one cell 80 over one channel can be maintained over another channel if the user PED 38 roams to other cells. For example, a user carrying a PED 38 can walk, from one cell 80 in which the PED is connected to the WLAN 10 via channel 1, into an adjacent cell 80 in which, for example, channel 6 is being used, and maintain the connection to the WLAN 10.

[0021] Communication between the PEDs 38 and the access points 18 is half-duplex. That is, in each frequency channel, at any one time either the access point

18 or one user PED 38 can transmit. PEDs communicate via CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance). That is, a PED 38 checks for a quiet channel before transmitting to its associated access point 18. If the channel is busy, the PED waits a random amount of time and then retransmits. Several PEDs 38 could transmit simultaneously when contending for channel use. If a collision of their signals is detected, each of the transmitting PEDs "backs off" and waits a random time period before retransmitting. Eventually one PED gains control of the channel and transmits.

[0022] The WLAN 10 is configured such that only access points 18 and PEDs 38 that meet applicable interference, health and safety requirements are allowed to operate within the network. PEDs that do not comply with such standards are excluded from connecting to the WLAN 10. More specifically, and for example, according to IEEE 802.11b protocol, each type of PED 38 that has passed testing for compliance with applicable interference, health and safety standards is identified in the MAC (Media Access Control) layer of the WLAN 10. Thus it can be determined at each access point 18 whether a remote PED 38 has been predetermined to be suitable for connection to the WLAN 10. If the PED is one that has been approved for connection, it is allowed to connect to the network; if not, the PED request for network access is ignored.

[0023] Configuring a WLAN for use in aircraft entails consideration of a variety of factors, including those related, for example, to aircraft and passenger safety. Not all of such factors, however, are unique to aircraft. Thus many of the considerations for configuring an aircraft WLAN also pertain to configuring a WLAN for use in other types of mobile platforms. Embodiments of a mobile WLAN as described above can be

configured in accordance with the following assumptions, determinations and considerations.

[0024]

[0025] Distance Assumptions and Far Field Calculations

[0026]

[0027] Emissions by 802.11b wireless LANs can be treated as a far field problem. The wavelength, λ , at 2.4 GHz is 0.125 meters. The far field limit is approximated by $2*d^2 / \lambda$ where "d" is the largest dimension of the transmitting antenna. For a typical omni-directional or patch antenna utilized at a wireless access point mounted, for example, in the overhead in an aircraft passenger cabin, the largest dimension is assumed to be approximately 9 inches or 0.23 meters. The far field limit for such an antenna 34, then, is approximately 0.85 meters.

[0028] A typical user PED 38 PCMCIA adapter antenna is assumed to have a largest dimension of 2 inches or 0.05 meters. The far field limit for such an antenna, then, is approximately 0.04 meters. Based on the foregoing assumptions and determinations, all WLAN 10 emissions more than one meter from an access point antenna 34 or more than four centimeters from a user PED 38 antenna can be treated as being in the far field.

[0029] Non-coaxial aircraft system cables can be lossy at the frequencies contemplated for use in the airborne WLAN 10. Therefore, possible effects of WLAN-radiated field levels at line replaceable units (LRUs) of an aircraft system are considered. An access point antenna 34 transmitting to users in an aircraft passenger compartment would be prevented by its ground plane (not shown) from radiating at

significant levels into the overhead compartment. Access point antenna 34 emissions, then, are investigated primarily for their effect on equipment in avionics bays under the floor or in the sidewalls of the aircraft. The user PED 38 antennas could radiate into both the overhead and underfloor areas of the aircraft. System LRUs can be installed in equipment bays and/or in the overhead throughout the aircraft. Therefore the minimum distance from an operating access point antenna 34 or a user PED 38 adapter to an airborne system LRU is assumed to be one meter.

[0030]

[0031] Field Strength Levels

[0032]

[0033] The following methodology is used to evaluate field strength levels for both aircraft system RF susceptibility and for RF exposure compliance. For the following analysis of field strength levels, it is assumed that a transmit antenna on either an access point or user adapter has a maximum gain value of 2.2 dBi (numerical value 1.66), and that transmit cable losses are zero dB. The far field radiated power density is given by:

[0034]
$$P_d = (P_t * G) / (4 * \pi * D^2) \quad (1)$$

[0035] where "P_t" is transmitter power at antenna input in watts, "G" is numerical gain of the transmit antenna relative to an isotropic source, and "D" is distance from center of transmit antenna to measuring point in meters.

[0036] The E-field in free space is given by:

[0037]
$$E \text{ (v/m)} = \text{SQRT} (P_d * 377), \text{ or} \quad (2)$$

[0038]
$$E \text{ (dBuv/m)} = 20 \text{ LOG}_{10} (E * 10^6) \quad (3)$$

[0039] where "E" is the E-field strength in volts per meter and "dBuv/m" is field strength in dB above 1 microvolt per meter. Referring to Figure 3, test data indicate that, for a single transmitter, transmitted power levels of both 1 and 3 milliwatts with a nominal unity gain (0 dBi) transmit antenna, the field strength is at or below 110 dBuv/m (0.3 volts per meter) for all distances greater than one meter. For multiple transmitters operating simultaneously using 802.11b protocol, field strength levels are analyzed as further described below.

[0040]

[0041] Maximum Permissible Exposure (MPE) Levels

[0042]

[0043] A 802.11b network operates in the 2.4 to 2.483 GHz ISM band. The IEEE C.95.1-1999 standard for human exposure to RF electromagnetic fields specifies a maximum permissible whole body exposure (MPE) level for this frequency region in an uncontrolled environment of $f/1500 \text{ mw/cm}^2$ averaged over 30 minutes, where f is frequency expressed in MHz. The worst case or minimum value is at the lower end of the frequency band where $\text{MPE} = 2400/1500 = 1.6 \text{ mw/cm}^2$ or 16 w/m^2 . The FCC requirement as specified in OET Bulletin 65 for this frequency range is 1.0 mw/cm^2 or 10 w/m^2 averaged over 30 minutes. Although the European CENELEC ES59005 maximum allowable RF exposure levels are less stringent than the FCC limits, the more conservative FCC requirements for compliance are used herein.

[0044]

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[0045] Maximum 802.11b Radiated Field Strengths

[0046]

[0047] It is assumed that over any 30-minute interval the separation distance from an individual to an access point antenna 34 in the overhead is 1.0 meters. Table 1 below describes 2.4 GHz WLAN radiated emissions at transmit powers from 1 to 100 milliwatts and at a transmitter-to-victim distance of 1 meter.

Table 1

2.4 GHz WLAN Radiated Emissions

Victim to Transmitter Distance = 1 m $\lambda = 0.125 \text{ m}$
Assume Tx antenna gain (dBi) = 2.2 = numeric 1.659587 Eff Area = 0.001875 m^2
short dipole

Transmit Power (mw)	Tx Power Density w/m^2	Tx Field Strength v/m	Tx Field Strength dBuV/m	Received Power w	Received Power dBm
1	0.000132066	0.223134	106.9713	2.48E-07	-36.06209
3	0.000396197	0.386479	111.7425	7.43E-07	-31.29087
5	0.000660329	0.498943	113.961	1.24E-06	-29.07239
10	0.001320657	0.705612	116.9713	2.48E-06	-26.06209
20	0.002641315	0.997886	119.9816	4.95E-06	-23.05179
30	0.003961972	1.222155	121.7425	7.43E-06	-21.29087
50	0.006603286	1.577796	123.961	1.24E-05	-19.07239
100	0.013206573	2.23134	126.9713	2.48E-05	-16.06209

[0048] Referring to Table 1, test data indicate that an 802.11b system radiating at 3 mw maximum output power will generate a radiated power density of $4 \times 10^{-4} \text{ w/m}^2$ at the distance of 1 meter from the access point antenna 34. This power density is 4.0×10^{-5} times the maximum allowed FCC level, which is equal to a margin of 44 dB.

[0049] It is possible for tall individuals to be within 0.25 meters of an overhead access point antenna 34 in a single-aisle aircraft or for a user to be within 0.05 meters of his/her PED 38 antenna. Table 2 below describes 2.4 GHz WLAN radiated emissions at transmit powers from 1 to 100 milliwatts and at a transmitter-to-victim distance of 0.05 meter.

Table 2

2.4 GHz WLAN Radiated Emissions

Victim to Transmitter Distance = 0.05 m $\lambda = 0.125 \text{ m}$
Assume Tx antenna gain (dBi) = 2.2 = numeric 1.659587 Eff Area = 0.001875 m^2
short dipole

Transmit Power (mw)	Tx Power Density w/m^2	Tx Field Strength v/m	Tx Field Strength dBuV/m	Received Power w	Received Power dBm
1	0.052826292	4.46268	132.9919	9.9E-05	-10.0415
3	0.158478876	7.729588	137.7631	0.000297	-5.27027
5	0.26413146	9.978856	139.9816	0.000495	-3.05179
10	0.52826292	14.11223	142.9919	0.00099	-0.04149
20	1.056525839	19.95771	146.0022	0.001981	2.968814
30	1.584788759	24.4431	147.7631	0.002971	4.729727
50	2.641314598	31.55591	149.9816	0.004952	6.948214
100	5.282629196	44.6268	152.9919	0.009905	9.958514

[0050] Table 3 below describes margins of compliance with FCC OET Bulletin 65 for worst-case exposure with access points separated by 3 meters and with multiple transmitters.

Table 3

Worst Case Exposure with Multiple Transmitters
Compliance Margins for FCC OET Bulletin 65 Reqmt

Seat spacing (row) = 0.8 m in = 31.496 Self Dist = 0.05 m
Seat spacing (side) = 0.5 m in = 19.685 FCC Rqmt 10w/m²
Access Pt Spacing = 3 m
Assume Tx antenna gain (dBi) = 2.2 = numeric 1.659587

Single Emitter	
Tx Pwr = 3	
Distance m	Pwr Dens w/m ²
0.75	0.000704
0.7	0.000809
0.6	0.001101
0.5	0.001585
0.4	0.002476
0.3	0.004402
0.25	0.006339
0.2	0.009905
0.1	0.03962
0.05	0.158479

Two & Four Adjacent Emitters + Own @ 0.05 meter
Tx Pwr = 3 mw

Dist-TX#1 m	Dist-TX#2 m	Two+own w/m ²	Two+own Margin dB	Single Margin dB	Four+own w/m ²	Four+own Margin dB
0.25	0.75	0.165522	17.81143	41.52211	0.166931	17.77463
0.3	0.7	0.16369	17.85979	40.92285	0.165098	17.82257
0.4	0.6	0.162056	17.90336	39.58391	0.163464	17.86577
0.5	0.5	0.161648	17.91428	38.00029	0.163057	17.8766
0.6	0.4	0.162056	17.90336	36.06209	0.163464	17.86577
0.7	0.3	0.16369	17.85979	33.56331	0.165098	17.82257
0.75	0.25	0.165522	17.81143	31.97969	0.166931	17.77463
0.8	0.2			30.04149		
0.9	0.1			24.02089		
0.95	0.05			18.00029		

Exposure from Two Adjacent Access Pts
Tx Pwr = 3 mw

Dist-TX#1 m	Dist-TX#2 m	PwrDens w/m ²	Margin dB
0.25	2.75	0.006392	31.94394
0.3	2.7	0.004457	33.51002
0.4	2.6	0.002535	35.96049
0.5	2.5	0.001648	37.82995
0.6	2.4	0.001169	39.32062
0.7	2.3	0.000883	40.53813
0.8	2.2	0.000701	41.54333
0.9	2.1	0.000579	42.37342
1	2	0.000495	43.05179
1.1	1.9	0.000437	43.59334
1.2	1.8	0.000397	44.0075
1.3	1.7	0.000372	44.30008
1.4	1.6	0.000357	44.47446
1.5	1.5	0.000352	44.53241

[0051] Referring to Tables 2 and 3, test data indicate that an 802.11b system radiating at 3 mw maximum output power will generate a radiated power density of 6.3×10^{-3} w/m² at the worst-case minimum distance of 0.25 meters from the access point antenna 34 and 1.6×10^{-1} w/m² at the worst-case minimum distance of 0.05 meters from the user PED 38 antenna. For the access point antenna 34, this power density is 6.3×10^{-4} of the maximum allowed FCC level, which is equal to a margin of 32 dB. For the user PED 38 antenna, this is 1.6×10^{-2} of the maximum allowed FCC level, which is equal to a margin of 18 dB.

[0052]

[0053] Contribution from Multiple WLAN Sources

[0054]

[0055] The contribution of multiple WLAN RF emission sources simultaneously transmitting is addressed next. Referring to Figure 2, the width 92 of

each seat 84 is assumed to be 0.5 meters. The seat pitch 96 is assumed to be 0.8 meters (32 inches) and the distance 100 between access point antennas 34 is assumed to be a minimum of 2.5 to 3 meters. Thus it is assumed that the worst-case RF levels are generated by multiple users transmitting via PEDs 38 while sitting in the seats 84 or otherwise closely spaced in the cell areas 80. It is assumed that the user PEDs 38 transmit simultaneously when they contend for the RF medium as previously described. Such simultaneous transmissions occur only for short periods of time (before one PED is granted access to transmit), compared to the 30-minute exposure time described above in connection with the FCC maximum allowed level of power density. The possibility nevertheless is considered, however, that such transmissions might generate RF signal levels that might interfere with airframe systems. It also is assumed that these asynchronous sources are in phase and that their transmitted signals will add constructively, even though this is unlikely.

[0056] A layout of a plurality of PEDs 38 in adjacent seats 84 is shown in Figure 4. The predominant source of EMI is likely to be a user's own laptop 38 antenna, which was assumed above to be at the worst-case distance of 0.05 meters from the user. Figure 5 shows margins of compliance to FCC emission requirements for a single laptop and for a laptop adjacent to other laptops. At the assumed seat width of 0.5 meters, the effect of one adjacent emissions source diminishes as the user approaches (e.g. leans toward) the other source. The seat pitch is assumed to be 0.8 meters (32 inches). Therefore the contributions from sources in seat rows in front of or behind the subject will not significantly affect the margin of compliance. As shown in Table 3, including two more sources at 0.75 meters (directly in front and in back of the subject

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laptop and transmitting at 3 mw) to the two sources in the same seat group plus the subject's laptop will only change the margin for RF exposure compliance from 17.81 to 17.77 dB.

[0057]

[0058] Radiated Cell Dimensions

[0059]

[0060] Cell size is determined based on the contemplated power level for the WLAN, the aggregate bandwidth contemplated to be available, and the number of users contemplated to share the bandwidth. For example, in the embodiment shown in Figure 2, a cell population of 3 rows includes 18 seats per access point. Such could be the case for a narrow body aircraft, e.g. a Boeing 737 or 757. A cell population of three rows on a wide body, e.g. a Boeing 767 or 200, could include 21 seats. A worst-case demand for bandwidth is likely to be for users requesting streaming video services. While systems using 802.11b protocol have been demonstrated to provide up to 8 Mbps per access point, a bandwidth of 6 Mbps is assumed to be achievable on a repeatable basis using standard hardware components. Thus it is assumed that a maximum aggregate bandwidth of 6 Mbps is available per access point 18 using short transmission preambles, and that typically 30 percent, *i.e.* 6 or 7 user PEDs 38, in a cell 80 are active and sharing the 6 Mbps bandwidth. Less bandwidth-demanding services such as e-mail or Internet access can support more users per access point 18. It is contemplated that power radiated by components of the WLAN 10 is kept in the 1- to 5-mw range in order to meet interference, health and safety requirements.

[0061]

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[0062] Received Signal Strength

[0063]

Table 4 below describes 2.4 GHz WLAN radiated emissions at transmit powers from 1 to 100 milliwatts and at a transmitter-to-victim distance of 3 meters. Assuming a maximum distance of 3 meters between an access point and its cell boundary, as shown in Table 4, a user PED 38 at the maximum distance from an access point antenna 34 broadcasting at 1 milliwatt receives a signal in the range of -45 to -50 dBm. This signal exceeds the 802.11b-specified value of -76 dBm required to support 11 Mbps communication. Such margin protects against signal fading due to mulltipath within the aircraft cabin.

Table 4

2.4 GHz WLAN Radiated Emissions

Victim to Transmitter Distance = 3 m $\lambda = 0.125 \text{ m}$
Assume Tx antenna gain (dBi) = 2.2 = numeric 1.659587 Eff Area = 0.001875 m^2
short dipole

Transmit Power (mw)	Tx Power Density w/m^2	Tx Field Strength v/m	Tx Field Strength dBuv/m	Received Power w	Received Power dBm
1	1.4674E-05	0.074378	97.42889	2.75E-08	-45.60451
3	4.40219E-05	0.128826	102.2001	8.25E-08	-40.8333
5	7.33698E-05	0.166314	104.4186	1.38E-07	-38.61481
10	0.00014674	0.235204	107.4289	2.75E-07	-35.60451
20	0.000293479	0.332629	110.4392	5.5E-07	-32.59421
30	0.000440219	0.407385	112.2001	8.25E-07	-30.8333
50	0.000733698	0.525932	114.4186	1.38E-06	-28.61481
100	0.001467397	0.74378	117.4289	2.75E-06	-25.60451

[0064] RF Susceptibility Test Levels For Aircraft Equipment

[0065]

[0066] Aircraft systems have been qualified to varying RF susceptibility test levels and frequency ranges. Those systems that have been determined to be flight-critical and essential are required to demonstrate immunity to the effects of High Intensity Radiated Fields (HIRF) and have been tested to field strengths that are many orders of magnitude above the RF field strength generated by an 802.11b WLAN system. Other systems qualified to levels below the HIRF levels also have demonstrated RF immunity in the 2.4 to 2.483 GHz frequency range. For any aircraft system for which there is no radiated susceptibility test data in the 802.11b operating band of 2.4 to 2.483 GHz, it is proposed that aircraft level susceptibility testing be performed to demonstrate that there will be no interference from the worst case operation of an 802.11b wireless LAN configured in accordance with the embodiments described herein.

[0067] The above-described WLAN 10 includes multiple intentional RF transmitters that operate at very low levels of RF field strength. These low levels provide significant margins of compliance for both electromagnetic interference and RF exposure limit regulations for operators, airframe manufacturers, and the traveling public. This makes it possible to safely operate the above-described WLAN 10 on board commercial aircraft in flight.

[0068] The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.